

Appendix F – GPRA05 Geothermal Technologies Program Documentation

Description of Assumptions that Support the GPRA 05 Benefits Analysis

The primary goal of the Geothermal Technologies Program is to reduce the cost of geothermal generation technologies, including both conventional and enhanced geothermal systems (EGS). Estimating the GPRA benefits involves projecting the market share for these technologies based on their economic and environmental characteristics.

Market Segments

Geothermal power is expected to penetrate in two market segments: the least-cost power market and the green power market. Only centrally located geothermal power plants were considered, although there is emerging industry interest in distributed applications, and there is a new DOE program to explore small-scale modular geothermal plant technology development (<5 MW).

- **Least-Cost Power**
NEMS-GPRA05 and MARKAL-GPRA05 were run to estimate market penetration into the competitive bulk power marketplace for geothermal power technologies. The program goals for geothermal technology improvements are modeled directly by incorporating the capital and operation and maintenance (O&M) cost reductions. The models also take into account site availability and maximum development per site per year for conventional and EGS geothermal capacity. The conventional geothermal characteristics modeled are from the EPRI/DOE *Renewable Energy Technology Characterizations*¹ report. The EGS characteristics were developed by Princeton Energy Resources International (PERI) in 2003.
- **Green Power**
Flash, binary, and EGS technologies were all modeled as potential geothermal power plants that could be installed to meet the emerging green power market. Flash and binary technologies compete well within the green power market, with flash technology out-gaining binary due to its more attractive cost curve. EGS technologies have significant cost penalties that restrict capacity additions until after 2015, and even then only a very limited amount of EGS power is projected to be built to meet green power demand. Although geothermal plants were limited to the western portion of the United States, they were typically one of the least-expensive options, leading to significant penetration in those two regions. The projections for green power geothermal installations were incorporated into the NEMS-GPRA05 and MARKAL-GPRA05 models as planned capacity additions.

¹ Renewable Energy Technology Characterizations, EPRI /DOE TR-109496, 1997.

Detailed Input and Methodology Information

NEMS-GPRA05

The NEMS-GPRA05 electricity-sector module performs an economic analysis of alternative technologies in each of 13 regions. Within each region, new capacity is selected based on its relative capital and operating costs, its operating performance (i.e. availability), the regional load requirements, and existing capacity resources. Geothermal capacity is treated in a unique manner due to the specific geographic nature of the resources. The model characterizes 51 individual sites of known hydrothermal geothermal resources, each with a set of capital and O&M costs. For the Program Case, three EGS sites in each of three regions were substituted for the most expensive hydrothermal sites in those regions.

Conventional Geothermal

Figure 1 illustrates the supply curve of the hydrothermal sites in the Northwest United States in 2006 and 2020 that can be developed in each of those years in NEMS-GPRA05. These curves reflect the GPRA cost reductions, as well as the financing assumptions from the *Annual Energy Outlook 2003 (AEO03)* Reference Case, and the limit of developing only 100 MW at a site each year. The limit of 100 MW development per site per year is an increase from the *AEO03* assumption of only 25 MW or 50 MW (depending on year). The limit change is made to reflect the program's efforts to reduce the risk associated with new geothermal development. The lowest part of the curve is not depicted for 2020, because it represents a portion of the capacity already developed.

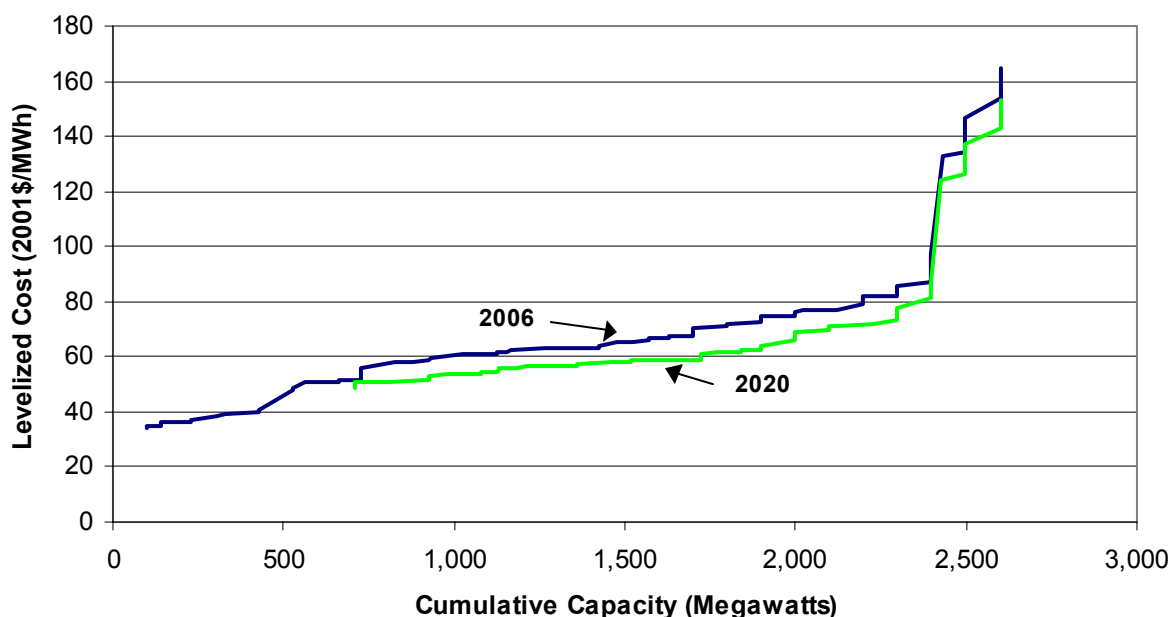


Figure 1. Geothermal Supply Curve – Northwest Region

Roughly 10 GW of hydrothermal resource in the Northwest and 23 GW in the lower 48 states is represented within NEMS-GPRA05. With the GPRA Base Case assumptions, much of this resource would be quite expensive to develop; today, an estimated 5 GW might be available at 6 cents per kWh.

Enhanced Geothermal Systems

Characteristics for EGS systems were also provided. Nine new EGS sites, were substituted for the three most expensive hydrothermal sites in the western regions: Northwest Power Pool (NWP, Region 11), Rocky Mountain Power Area, Arizona, New Mexico, and Southern Nevada (RA, Region 12), and California (CA, Region 13). Each site represents a Type of EGS resource:

- Type I. A site where EGS would be used to improve an existing commercial hydrothermal reservoir.
- Type II. A site where EGS would work to develop economic power from identified sites with sub-commercial hydrothermal features.
- Type III. A site where EGS would be used as a longer-term strategy to develop power systems in volumes of rock that have not been identified as hydrothermal prospects.

Similar to the conventional sites, each geothermal site is further specified in four stages of increasing costs (**Table 1**).

Table 1. EGS Site Characterization for NEMS-GPRA05

		Potential Capacity 1 (MW)	Potential Capacity 2 (MW)	Potential Capacity 3 (MW)	Potential Capacity 4 (MW)	Capacity Factor
Region 11	EGS Type I	550	550	550	550	0.9
	EGS Type II	2500	2500	2500	2500	0.9
	EGS Type III	5000	5000	5000	5000	0.9
Region 12	EGS Type I	0	0	0	0	0.9
	EGS Type II	1250	1250	1250	1250	0.9
	EGS Type III	5000	5000	5000	5000	0.9
Region 13	EGS Type I	300	300	300	300	0.9
	EGS Type II	2500	2500	2500	2500	0.9
	EGS Type III	5000	5000	5000	5000	0.9

Capital and O&M costs were provided for the initial development at each site and were the same for all regions. The EGS and conventional costs are shown below in 2001 dollars (**Table 2**).

Table 2. Geothermal Characteristics for NEMS-GPRA05

	2005	2010	2015	2020	2025
Capital Cost (2001\$/kW)					
Flash	1,342	1,282	1,232	1,181	1,147
Binary	2,141	2,013	1,883	1,758	1,691
EGS I	2,400	2,132	1,864	1,596	1,328
EGS II	2,760	2,452	2,144	1,835	1,527
EGS III	3,120	2,772	2,423	2,075	1,726
Total O&M Costs (2001\$/kW-yr)					
Flash	80.3	71.2	66.6	62.5	60.7
Binary	84.3	71.7	63.9	56.3	55.3
EGS I	150.0	132.0	114.0	96.0	78.0
EGS II	172.5	151.8	131.1	110.4	89.7
EGS III	195.0	171.6	148.2	124.8	101.4

MARKAL-GPRA05

The geothermal technologies represented in MARKAL-GPRA05 reflect the program goals for both conventional systems and EGS. For conventional geothermal systems, the capital and operating and maintenance costs were changed to reflect program goals. However, EGS represents a new geothermal resource not previously represented in the MARKAL-GPRA05 model. The program identified three separate types of potential geothermal reservoirs, as discussed above.

Due to program activities, the capital and O&M costs of EGS systems are projected to decline over time. **Table 3** shows the estimated capital and O&M costs for the three types of EGS systems for 2000 and 2050.

Table 3: EGS Generation Assumptions for MARKAL-GPRA05

EGS Type	Projected Resource MWe	2000 Cost		2050 Cost	
		Capital Cost	O&M	Capital Cost	O&M
		01\$/kW	01\$/kW/yr	01\$/kW	01\$/kW/yr
I	3,400	2,448	153	934	50
II	25,000	2,815	176	1,074	58
III	60,000	3,182	199	1,214	66

The EGS sites projected under the program are grouped into a set of supply steps and the discount rate of these technologies is set at 8% (instead of 10% for the industrial average) to reflect the accelerated depreciation schedule permitted by the IRS for renewable generation technologies. The EGS systems are modeled as centralized base-load generation.

Geothermal plants compete directly with fossil fuel-based plants for both electricity generation and meeting peak power requirements. In MARKAL-GPRA05, EGS becomes more competitive as its higher capital cost is offset by increased fossil fuel costs, which increase as demand increases.

Green Power Market Model

PERI used the Green Power Market model to project regional green power additions (**Table 4**). These capacity additions are used by NEMS-GPRA05 and MARKAL-GPRA05 as planned new capacity or minimum capacity additions.

Table 4. Incremental Green Power Geothermal Capacity Additions (MW)

	2004-2008	2009-2010	2011-2015	2016-2020	2021-2025	2004-2020
NWPP	1	26	60	54	29	170
RA	3	24	50	36	23	136
CNV	0	37	94	100	48	280
Total	4	87	204	190	100	585